Energy Efficient and Delay-Aware Adaptive Slot Allocation Medium Access Control Protocol for Wireless Body Area Network

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***Abstract*— Wireless Body Area Network (WBAN) is the cheapest solution using BioMedical Sensors. They monitor different physiological vital signs of a patient. The output of vital signs does not accept collision, delay, loss, and a high energy consumption of BMSs. This paper proposes Energy Efficient and Delay-Aware Adaptive Slots Allocation Medium Access Control (EED-MAC) Protocol for WBAN. This Proposed MAC provides sufficient and dedicated channels to all types of BMSs. The patient's data are divided according to the need of a patient. Moreover, the contentions of BMSs are reduced and does not drop data by proposing a Reduced Contention Adaptive Slots Allocation CSMA/CA (RCA-CSMA/CA) scheme. The third proposed scheme is Reliability-Aware Channel Allocation (RAC), which allocates channels for emergency-based BMSs using alert signals without contention. The simulation of the proposed MAC and other schemes achieve significant improvements against the state-of-the-art MAC protocols.**

Keywords—Medium Access Control; Superframe Structure, Channel, Patient's data

I. INTRODUCTION

Wireless Body Area Network (WBAN) is accomplishing interest to monitor different physiological health conditions of a patient's in the healthcare domain. BMSs are sewed or attached on different positions on skin of a patient to monitor temperature, blood pressure, heartbeat and respiratory rate [1]. Some BMSs are implanted inside the patient's body to monitor internal organs such as liver, heart, and kidney [2]. The handshaking, sleeping positions and durations [3][4] of a patient are the physical activities monitored with the support of the sensors. These types of sensors are placed in few centimeters. The monitored data are classified into Non-Constrained Data (NCD), Delay-Constrained Data (DCD), Reliability-Constrained Data (RCD) and Critical Data (CD) as used in [5]. The NCD data contains a normal reading of vital signs such as normal temperature and does not require any delay or reliability constraint. DCD data contains audio/video information about the patient such as sleeping positions, handshaking and accepts minimum packet loss. The RCD contains reading of high threshold values of vital signs such as high threshold of heart beat and accepts minimum delay with packet loss. The CD contains reading of low threshold values such as low threshold of respiratory rate and does not accept delay, packet loss which need to be delivered with highest reliability.

The monitored data of a patient need channels to transmit immediately. The Superframe structure of IEEE 802.15.4 MAC [6][7] is employed for these four types of data. This MAC includes a beacon, Contention-Access Period (CAP), Contention-Free Period (CFP) and Inactive period (IP). Before data communication, the coordinator broadcast a beacon in the star topology to BMSs. The beacon frame contains information about address of the coordinator, synchronization and Beacon Interval (BI) for Superframe structure. Moreover, the CAP period is implemented on CSMA/CA scheme and the CFP period is implemented on TDMA scheme. Each BMS tries to contend for accessing channel in CAP. The coordinator assigns the CFP's guaranteed timeslots to BMSs that achieved access for a channel in CAP. The contention-based channel allocation is causing collision due to limited channels in CAP, increases delay with lower data reliability, reduces throughput by retransmission of the collided data packets, and BMSs consumes a high energy. Also, the coordinator invokes a new beacon frequently, which reduces the performance of MAC protocol by not contending and data transmission in the same interval. Moreover, the contention repeats the previous rounds in the subsequent round. The standard CSMA/CA scheme uses (1), which repeats values of the contention as expressed.

$$NB = 0\ TO\ 2^{BE} - 1 \qquad (1)$$

Where NB is the number of back-off to access channel and BE is the back-off exponential. The minimum number of back-off is 3 and the maximum is 5. IEEE 802.15.4 does not allocate the dedicated channels to emergency data. The Preemptive slot allocation and Non-Preemptive (PNP-MAC) protocol [8] provides sufficient and dedicated channels to BMSs. These channels are assigned to BMSs based on the contention and the coordinator drops non-emergency data and assigns channels to

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emergency data using advertisement beacon when it arrives. It has the same challenging problems as aforementioned. The traffic priority and load adaptive MAC (PLA-MAC) protocol [9] also provides dedicated and sufficient channels to BMSs. On the successful allocation of the CAP's channels, the coordinator finds the criticality of the detected data and assigns channels. This MAC protocol does not resolve the conflict of the CFP's channels allocation between BMSs if the coordinator receives data in the same time. Recently developed MAC protocols are [10], PA-MAC [11], and MC-MAC [12] in WBAN, have the same challenging problems. Due to these problems, we propose EED-MAC protocol providing dedicated and sufficient channels. The contention is reduced by proposing RCA-CSMA/CA scheme. Further, this paper proposes RAC scheme which allocates channels to emergency data based on using of alert signals without contention.

This paper is constructed as: Section II presents EED-MAC Superframe structure, classification of a patient's data, working steps of RCA-CSMA/CA, and RAC schemes. The performance evaluation of the proposed schemes are compared with existing MAC protocols in Section III. The paper is concluded in Section IV.

II. Proposed works

A. Overview

The delay and reliability constraints data are presented in the traffic classification. Then, the novel proposed Superframe structure of EED-MAC is discussed.

B. Traffic Classification

The NCD and DCD are non-emergency data and the allocation of channels using RCA-CSMA/CA scheme, which reduces repetition of the contention by not dropping the patient's data. The RCD and CD, where these types of a patient's data do not contend to access channel and is using alert signals based allocation of channels. The RCA-CSMA/CA and RAC are discussed in Sections D and E, respectively.

C. Superframe structure of EED-MAC

The EED-MAC Superframe structure comprises of a beacon (B), CAP, Clear Channel Access (CCA), Contention-Missed Transfer Slots (CMTS), Data Transfer Slot for Normal data (DTSN), High Critical (HC), Data Transfer Slots for High Critical data (DTSHC), Low Critical (LC), Data Transfer Slots for Low Critical data (DTSLC) and IP, as shown in Fig. 1. These various frames occupy 64 channels. The coordinator allocates ten channels to CAP period, CCA occupies two channels, CMTS occupies six channels, DTSN occupies twelve channels; and DTSHC and DTSLC each of them occupy fourteen channels. The HC and LC each of them occupy 1 channel. The coordinator broadcasts a beacon frame containing address, synchronization, and beacon frame before data transmission. The address represents the coordinator as a head of the topology. In the synchronization, BMSs scan channels actively to contend for accessing CAP period. The coordinator allocates DTSN channels to BMSs that accessed a channel of the CAP. The proposed RCA-CSMA/CA scheme minimizes contention in rounds of BMSs, which is explained in the next section. However, the existing MAC schemes drop the patient's data without caring of the life-critical data. Moreover, the detected low threshold value, BMS is not contending to access CAP, but it sends an alert signal to the HC channel. The coordinator replies back by allocating DTSHC channels based on the criticality level of vital signs. The similar process is employed for the detection of high threshold values using LC frame and allocation of DTSLC channels. For this purpose, the proposed RAC scheme is presenting two algorithms, explained in the next section. The coordinator actives CMTS, DTSN, DTSCH, and DTSLC channels when it receives an alert signal in beacon frame which consumes minimum energy.

D. Reduced Contention Adaptive Slots Allocation CSMA/CA (RCA-CSMA/CA) Scheme

This proposed RCA-CSMA/CA decreases the rounds of contention of the NCD and DCD-based BMSs for accessing CAP. The reduced contentions of BMSs minimize collision of the data packets and delay with higher data reliability. Also, it decreases retransmission of the collided data packets and BMSs consume minimum energy. Further, the BMS does not drop the patient's data in exceeding of threshold values of contention to access CAP period. In this situation, that particular BMS performs twice CCA to assure collision-free access to CMTS channel. For reduced contention and allocation of channels, the (2) is introduced as expressed below.

$$\mathrm{NB} = 2^{\mathrm{BE}-1} \ \mathrm{To}\ 2^{\mathrm{BE}} - 1 \qquad (2)$$

Where NB is the number of back-off and BE is the back-off exponential. We set four rounds of contentions for accessing the CAP's channels. These rounds are round1=1, round2=2, round3=3, and round4 =4. Equation (1) of the CSMA/CA is used in the first round. For remaining rounds of the contention, (2) is used. For this purpose the proposed RCA-CSMA/CA algorithm is employed. Initially, we configure CW=2, NB=0, and BE=round1 in the RCA-CSMA/CA algorithm, as shown in step 1 and the control is transferred to step 2, as shown in the proposed algorithm. BMS defines the values of rounds of the contentions as shown in step 2 with the support of using (1), as depicted in step 3. In step 4, the BMS contends for accessing channel in the CAP period and decrements the values of CW before allocating channel, as shown in step 5. The control is transferred to step 4 if BMS expires the values of CW and does not access CAP. If a channel is busy, then the value of CW is set 2 and the values of NB is incremented by one. Here, the coordinator verifies the condition whether the particular BMS has exceeded the contention or not, as shown in step 6. If the condition is true, that BMS goes for the second round of the contention using (2). Further, we consider that BMS has not obtained a channel in the CAP period and will go for third round of the contention. The same contention processes are used for third round. Similarly, the fourth round of contention is used if the BMS has not accessed a channel in the previous rounds. Thus, the reduced contention of the RCA-CSMA/CA scheme is

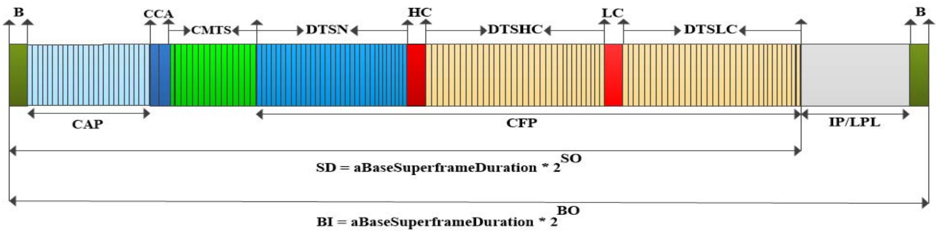

Fig. 1: The Proposed EED-MAC

0 to 1 in the first, 2 to 3 in the second, 4 to 7 in the third, and 8 to 15 in the fourth round. Another novel solution of this algorithm is that BMS does not drop the patient's data if BMS exceeds threshold value of the contention. The particular BMS performs twice a CCA to assure for collision-free access of CCA channel. On the successful allocation of CCA channels, the coordinator allocates CMTS channel. The proposed algorithm is presented in the following.

Algorithm: Reduced contention adaptive slots allocation CSMA/CA (RCS-CSMA/CA)

Notations

CW: Size of Contention Window
NB: Number of Back-offs
CCA: Clear Channel Assessment
BE: Back-off Exponential
Round1= 1st round of contention
Round2: 2nd round of contention
Round3: 3rd round of contention
Round4: 4th round of contention
2^{BE-1}: Defines Minimum BE
2^{BE} - 1: Defines Maximum BE

Input

CW=2, NB=0, BE=0, Node_x, CCA=2, round1, round2 =2, round3 =3, round4 =4

Process

```
  START
1. Set CW=2, NB=0, BE=round1  [step 1]
2. for (Node ∑_{x=1}^{k} ∈ uses fixed backup OR not using fixed backup)
       Set BE ← min (1, round1)
       Go to [step 2]
3. Define boundaries of back-off [step 2]
4. Set NB ← (0 To 2^BE -1) [step 3]
5. Set Node_x ← use CCA on the defined boundaries in NB [step 4]
6. if (status_of_CAP_channel = Free)
       Set CW ← CW-1  [step 5]
       if (CW = 0 AND CAP's have channel)
           send Data
       else Twice perform CCA and back to [step 4]
       end if
7.  else
       Set CW ← 2
       Set NB ← NB+1;
       Set BE ← min (BE++, round4)  [step 6]
8.        if (NB=round2)
            Set round2 ← 2
            Set BE ← round2
          Delay for random [Compute NB = 2^{BE−1} To 2^BE – 1] AND back
           to [step 4]
         else if (NB = round3)
          Set round3 ← 3
           Set BE ← round3
          Delay for random [Compute NB = 2^{BE−1} To 2^BE – 1] AND back
           to [ step 4]
        end if
     else
          Set round4 ← 4
          Set BE ← round4
          Delay for random [Compute NB = 2^{BE−1} To 2^BE – 1] AND back
           to [step 4]
        end if
     else if (NB > round4)
          Set Twice use CCA for obtaining CCA ∑_{w=1}^{z} channel
9.     if (CCA_channel_status = Free)
           Set CCA ← BMS_x uses alert
           BMS_x ←coordinator_assigns_CMTS_channel (W)
           CMTS (W) ← BMS_x
          Else  wait for next BI
      end if
    End
```

Output: Reduction of contention and allocation of channels to BMSs

E. Reliability-Aware Channel Allocation (RAC) Schemes

The *RCD and CD-based BMSs do not accept delay and* packet loss. BMS sends an alert signal to HC channel in detection of low threshold of a vital sign. The coordinator replies back by activating and allocation of DTSHC channels to it. Also, the coordinator resolves the conflict of channels allocation and allocates DTSHC channels to BMSs based on the criticalites of vital signs when the coordinator receives alert signal of two BMSs in the same time. For this purpose, (3) is using for allocating of channels based on the priority as follows.

$$\text{Priority\_based\_Channel\_Allocation} = \frac{\text{Th\_Val}}{\text{Rate\_Generation} * \text{Ps}} \quad (3)$$

Where *priority_based_channel_allocation* is the allocation of channel to severity of vital signs, *Th_val* is the detected threshold value of the particular vital sign, *Rate_ Generation* is the recently (Re) or early (Ea) timing of the generated data, and *Ps* is the size of data measured in bytes. The algorithm is proposed for low threshold values of two vital signs considering two scenarios. In case of single BMS transmit the detected low threshold of a vital sign; the coordinator allocates DTSHC without verifying other parameters, as shown in (3). The scenario two presents two BMSs, where they detected low threshold of vital signs and transmit to coordinator using HC channel at the same. We have divided values of low thresholds into low1 (L1) and low2 (L2). The L1 is approaching ahead to zero value while values of L2 is beyond values of L1. Hence, the first DTSHC channel allocation is to L1 and then secondly is to L2 if L1 is generated with Ea. If the coordinator receives L2 with Ea as compared L1 with Re. In this case, the coordinator assigns first channel to L2 and secondly assigns to L1. The reason is that L2 has generated earlier than L1 and cannot be delayed. If both low thresholds are of the same values i.e. L1 or L2 with Ea or Re. In this case, the coordinator allocates DTSHC channels in ascending order, accordingly.

Algorithm for Low threshold: The coordinator finds severities of low threshold and assigns DTSHC based on the priority.

Notations

Vital_signs_Monitor: Heterogeneous nature of patient data
TH_Val: Contain values of low threshold
$BMS_r \ldots r_s$: Deployed BMSs is monitoring various vital signs of a patient body
DTSHC: Data Transfer Slot for High Critical in the detection of low threshold
C: Coordinator is responsible to allocate DTSHC slots in emergency situation.
HC: Emergency beacon for the low threshold value to receive alert signals
Ea _G: Time of earlier generated data
Re_G: Time of recently generated data
Ps: information of a patient data in bytes
C_Allc_DTSHC: The coordinator assigns DTSCH channels to values of low detected threshold
C_L1: Contains the first highest low threshold value reading
C_L2: Contains the second highest low threshold value reading

Input

L1 and L2 values are the inputs coming from sensors and forward to the coordinator

Process

START
1.Vital_signs_Monitor ← $\sum_{r=1}^{s}$ BMSs
2. **for** (each BMS transmit Th_Val belongs to Low) **do**
3.**if** (HC_C ← Transmits_alert_of_detected_$\sum_{r=1}^{s}$ BMSs) **then**
4. **if** (C ← received_Low_Threshold_value_from_single_sensor) **then**
5. **if** (BMS{$TH_{-val}{}_r^s$}_detected = = Low_Th_Val && ∈ ($Re\_G_r^s$ **OR** $Ea\_G_r^s$) && $Ps_{\_r\,or\,s} \neq 0$) **then**
$\sum_{r=1}^{s}$ BMS ← C_allocates_Slot_DTSHC(Wx)
else Go To Monitoring status
else if (C_received_alerts_in_HC == Low_Th_Vals && ∈ {$TH_{\_Val}{}_r^s$} BMSs) **then**
6. **if** (BMS_r_detected_Th_val == C _L_1 && Ea_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_1 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
7. **else if** (BMS_r_detected_Th_val == C _L_1 && Ea_G_r && $Ps_{-r} \neq 0$) > (BMS_s_detected_Th_val == C _L_1 && Re_G_s && $Ps_{-r} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
8. **else if** (BMS_r_detected_Th_val == C _L_1 && Re_G_r && $Ps_{-r} \neq 0$) < (BMS_s_detected_Th_val == C _L_1 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSHC (W_k) **AND** BMS_r←C_Allc_DTSHC (W_{k+1})
9. **else if** (BMS_r_detected_Th_val == C _L_1 && Re_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_1 && Re_G_n && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSHC (W_k) **AND** BMS_r←C_Allc_DTSHC (W_{k+1})
10. **else if** (BMS_r_detected_Th_val == C _L_1 && Ea_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_2 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
11. **else if** (BMS_r_detected_Th_val == C _L_1 && Ea_G_r && $Ps_{-r} \neq 0$) > (BMS_s_detected_Th_val == C _L_2 && Re_G_s && $Ps_{-r} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
12. **else if** (BMS_r_detected_Th_val == C _L_1 && Re_G_r && $Ps_{-r} \neq 0$) < (BMS_s_detected_Th_val == C _L_2 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSHC (W_k) **AND** BMS_r←C_Allc_DTSHC (W_{k+1})
13. **else if** (BMS_r_detected_Th_val == C _L_1 && Re_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_2 && Re_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
14. **else if** (BMS_r_detected_Th_val == C _L_2 && Ea_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_1 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSHC (W_k) **AND** BMS_r←C_Allc_DTSHC (W_{k+1})
15. **else if** (BMS_r_detected_Th_val == C _L_2 && Ea_G_r && $Ps_{-r} \neq 0$) > (BMS_s_detected_Th_val == C _L_1 && Re_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
16. **else if** (BMS_r_detected_Th_val == C _L_2 && Re_G_r && $Ps_{-r} \neq 0$) < (BMS_s_detected_Th_val == C _L_1 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSHC (W_k) **AND** BMS_r←C_Allc_DTSHC (W_{k+1})
17. **else if** (BMS_r_detected_Th_val == C _L_2 && Re_G_r && $Ps_{-r} \neq 0$) == BMS_s_detected_Th_val == C _L_1 && Re_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
18. **else if** (BMS_r_detected_Th_val == C _L_2 && Ea_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_2 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
19. **else if** (BMS_r_detected_Th_val == C _L_2 && Ea_G_r && $Ps_{-r} \neq 0$) > (BMS_s_detected_Th_val == C _L_2 && Re_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
20. **else if** (BMS_r_detected_Th_val == C _L_2 && Re_G_r && $Ps_{-r} \neq 0$) < (BMS_s_detected_Th_val == C _L_2 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSHC (W_k) **AND** BMS_r←C_Allc_DTSHC (W_{k+1})
21. **else if** (BMS_r_detected_Th_val == C _L_2 && Re_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _L_2 && Re_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSHC (W_k) **AND** BMS_s←C_Allc_DTSHC (W_{k+1})
22. **else monitor a patient body in sleep mode**
23. **end if**
24. **end if**
25. **end if**
26. **end for**
END

Output: DTSHC channels are assigned to low threshold values on the severities-basis.

This algorithm is proposed for high threshold values and the allocation of DTSLC channels using (3). The high threshold values of a vital sign are divided into high1 (H1) and high2 (H2). The H2 is near to the normal value ranges while H1 is far away from ranges of H2. The same steps of channels allocations are used for high threshold values of vital signs as followed for low threshold values. The detected high threshold based BMS transmit an alert signal to LC channel of the coordinator. The coordinator replies back by activating and allocation of DTSLC channels, based on severities of vital signs. The proposed algorithm for DTSLC is presented in the following.

Algorithm for High threshold: The coordinator finds severities of low threshold and assigns DTSLC based on the priority.

Notations

Vital_signs_Monitor: Heterogeneous nature of patient data
TH_Val: Contain values of low threshold
$BMS_r \ldots r_s$: Deployed BMSs is monitoring various vital signs of a patient body
DTSLC: Data Transfer Slot for High Critical in the detection of low threshold
C: Coordinator is responsible to allocate DTSHC slots in emergency situation.
LC: Emergency beacon for the low threshold value to receive alert signals
Ea _G: Time of earlier generated data
Re_G: Time of recently generated data
Ps: information of a patient data in bytes
C_Allc_DTSLC: The coordinator assigns DTSLC channels to values of low detected threshold
C_H1: Contains the first highest low threshold value reading
C_H2: Contains the second highest low threshold value reading

Input

H1 and H2 values are the inputs coming from sensors and forward to the coordinator

Process

START
1. Vital_signs_Monitor ← $\sum_{r=1}^{s}$ BMSs
2. **for** (each BMS transmit Th_Val belongs to High) **do**
3. **if** (LC_C ← Transmits_alert_of_detected_$\sum_{r=1}^{s}$ BMSs) **then**
4. **if** (C ← received_High_Threshold_value_from_single_sensor) **then**
5. **if** (BMS{$TH_{-val}{}_r^s$}_detected = = High_Th_Val && ∈ ($Re\_G_r^s$ **OR** $Ea\_G_r^s$) && $Ps_{\_r\,or\,s} \neq 0$) **then**
$$\sum_{r=1}^{s} \text{BMS} \leftarrow \text{C\_allocates\_Slot\_DTSLC(Wx)}$$
else Go To Monitoring status
else if (C_received_alerts_in_LC ==High_Th_Vals && ∈ {$TH_{\_Val}{}_r^s$} BMSs) **then**
6. **if** (BMS_r_detected_Th_val == C _H_1 && Ea_G_r && $Ps_{-r} \neq 0$) == (BMS_s_detected_Th_val == C _H_1 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_r←C_Allc_DTSLC (W_k) **AND** BMS_s←C_Allc_DTSLC (W_{k+1})
7. **else if** (BMS_r_detected_Th_val == C _H_1 && Ea_G_r && $Ps_{-r} \neq 0$) > (BMS_s_detected_Th_val == C _H_1 && Re_G_s && $Ps_{-r} \neq 0$) **then** BMS_r←C_Allc_DTSLC (W_k) **AND** BMS_s←C_Allc_DTSLC (W_{k+1})
8. **else if** (BMS_r_detected_Th_val == C _H_1 && Re_G_r && $Ps_{-r} \neq 0$) < (BMS_s_detected_Th_val == C _H_1 && Ea_G_s && $Ps_{-s} \neq 0$) **then** BMS_s←C_Allc_DTSLC (W_k) **AND** BMS_r←C_Allc_DTSLC (W_{k+1})

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else if (BMS_r_detected_Th_val == C_H_1 && Re_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_1 && Re_G_n && Ps_-s ≠ 0) then
    BMS_s←C_Allc_DTSLC (W_k) AND BMS_r←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_1 && Ea_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_2 && Ea_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_1 && Ea_G_r && Ps_-r ≠ 0) >
    (BMS_s_detected_Th_val == C_H_2 && Re_G_s && Ps_-r ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_1 && Re_G_r && Ps_-r ≠ 0) <
    (BMS_s_detected_Th_val == C_H_2 && Ea_G_s && Ps_-s ≠ 0) then
    BMS_s←C_Allc_DTSLC (W_k) AND BMS_r←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_1 && Re_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_2 && Re_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Ea_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_1 && Ea_G_s && Ps_-s ≠ 0) then
    BMS_s←C_Allc_DTSLC (W_k) AND BMS_r←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Ea_G_r && Ps_-r ≠ 0) >
    (BMS_s_detected_Th_val == C_H_1 && Re_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Re_G_r && Ps_-r ≠ 0) <
    (BMS_s_detected_Th_val == C_H_1 && Ea_G_s && Ps_-s ≠ 0) then
    BMS_s←C_Allc_DTSLC (W_k) AND BMS_r←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Re_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_1 && Re_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Ea_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_2 && Ea_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Ea_G_r && Ps_-r ≠ 0) >
    (BMS_s_detected_Th_val == C_H_2 && Re_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Re_G_r && Ps_-r ≠ 0) <
    (BMS_s_detected_Th_val == C_H_2 && Ea_G_s && Ps_-s ≠ 0) then
    BMS_s←C_Allc_DTSLC (W_k) AND BMS_r←C_Allc_DTSLC (W_k+1)
else if (BMS_r_detected_Th_val == C_H_2 && Re_G_r && Ps_-r ≠ 0) ==
    (BMS_s_detected_Th_val == C_H_2 && Re_G_s && Ps_-s ≠ 0) then
    BMS_r←C_Allc_DTSLC (W_k) AND BMS_s←C_Allc_DTSLC (W_k+1)
else  monitor a patient body in sleep mode
      end if
      end if
   end if
end for
END
```

Output: DTSLC channels are assigned to high threshold values on the severities-basis.

III. Performance Evaluation

The simulations are performed in NS2 considering 10 BMSs. IEEE 802.15.4 MAC, PNP-MAC [8], and PLA-MAC [9] are compared with the proposed MAC protocol in terms of delay, throughput, and energy. All MAC protocols are configured with Beacon Order (BO) 8 and Superframe Order (SO) is 7. Table I presents simulation parameters used in NS2.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Frequency Band in MHz	2.4 GHz
No. of Nodes	10
Coordinator	1
Simulation Area	4*3 m
Data Packet Size	50 bytes
Data Packet Duration	15.5 ms
Channel data Rate	250 kbps
No. of Slots in Proposed MAC Superframe	64
CAP slots in IEEE 802.15.4 MAC, PLA-MAC	8 and 20 slots
CAP slots in the proposed EED-MAC	10 slots
Propagation Type	TwoRayGround
Traffic Type	CBR
Beacon duration	3.2 ms
Max. number of backoff	4
Transmission (T_X) energy used	27 mW
Sleep state (PS) energy used	5 µW
Receive (R_X) state energy used	1.8 mW
Switching to Tx or Rx	0.8 ms
Energy needed between switching to T_X and R_X, and vice-versa	0.4 ms
Topology	Star

The channels allocation to all types of BMSs either their data packets contains emergency or non-emergency data, is based on the contention as observed in state-of-the-art MAC protocols. As shown in Fig. 2, the average packet delivery delay is high in IEEE 802.15.4 and PNP-MAC due to limited channels in the CAP period, increased and repeated values of the contention and is frequently invoking of BO and SO. PLA-MAC performs better than IEEE 802.15.4 and PNP-MAC, but is not performing better as compared to the proposed EED-MAC. The EED-MAC has reduced the contention for non-emergency data and does not drop the patient's data by using CMTS channels with the support of CCA channels. Also, it allocates dedicated channels to emergency based BMSs without contention in emergency situations.

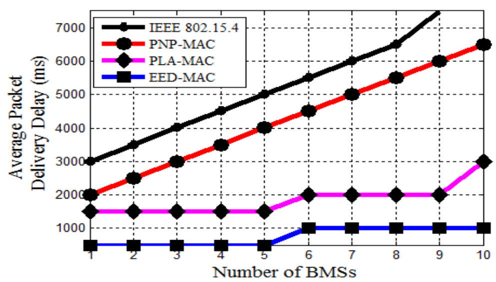

Fig. 2. Average Delay of Packet Delivery V/s number of BMSs

The limited channels in CAP period, non-allocation of dedicated channels, contention-based channels allocation, BMSs cannot contend and transmit data in the same BO and SO, have been observed in IEEE 802.15.4 MAC and PNP-MAC. These factors reduce throughput performance suddenly when traffic load exceeds from seven BMSs as shown in Fig. 3. Also, the PNP-MAC preempts non-emergency data from the allocated channels on the arrival of emergency data by reducing throughput. Moreover, PLA-MAC allocates channels based on the contention and throughput decreases as more BMSs contend and transmit data. The proposed EED-MAC performs better than addressed MAC protocols due to sufficient channels, the dedicated assignment of channels to all BMSs, and reduced contention. Moreover, BMSs perform contention and send sensory data in the same BO and SO. In addition, the EED-MAC is not dropping the life critical data of a patient by assigning CMTS channels.

The contention-based channels allocation causes collision due to limited channels and delay with transmission of the collided packet as observed in IEEE 802.15.4, PNP-MAC and PLA-MAC. The frequent calling of BO and SO; and contention consume a high energy of BMSs, as shown in Fig. 4. The proposed EED-MAC based BMSs consume a minimum energy due to sufficient channels in the CAP period, reduced contention and dedicated channels allocation to BMSs, as shown in Fig. 4. Fig. 5 shows energy consumption of the coordinators of IEEE 802.15.4, PNP-MAC and PLA-MAC. The coordinators cannot de-activate channels of their Superframe structures and cannot switch off in sleep mode due to limited channels and contention which causes collision with delay. Moreover, BMSs retransmit the collided data packets as addressed in three MAC protocols. However, the proposed EED-MAC keeps de-active channels that are CMTS, DTSN, DTSHC and DTSLC when there is no traffic of BMSs being to transmit. In this way, the coordinator consumes minimum energy, as shown in Fig. 5.

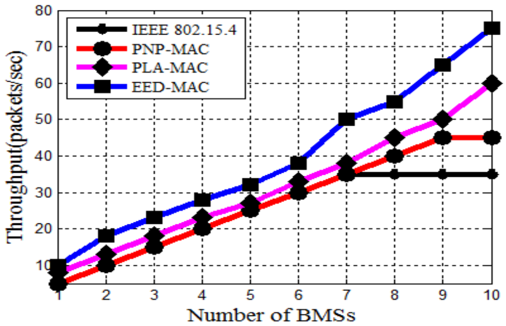

Fig. 3. Average Throughput V/s number of BMSs

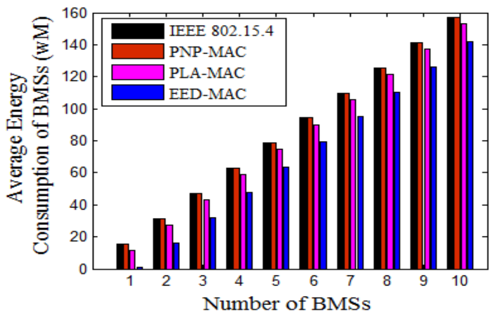

Fig. 4. Average Energy Consumption of BMSs V/s BMSs

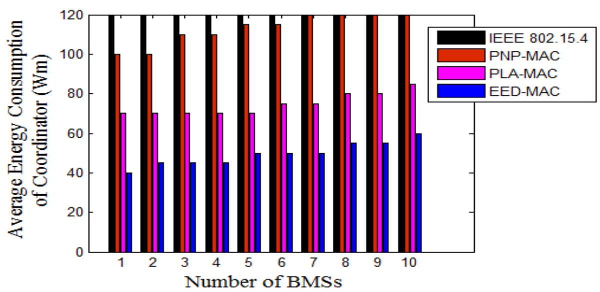

Fig. 5. Coordinator Average Energy Consumption V/s BMSs

IV. Conclusion

The proposed EED-MAC protocol provides sufficient channels to all types of a patient's data. The contention has been reduced using RCS-CSMA/CA scheme, which assists in dropping of the important data of a patient. Also, the proposed RCA scheme allocates dedicated channels to low and high threshold values of vital signs without contention. The RCA resolves conflict of channel allocation between BMSs. The proposed MAC protocol and other schemes reduces delay and energy consumption; and improves throughput as compared to IEEE 802.15.4, PNP-MAC and PLA-MAC.

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